Lessons Learned From The PV Hybrid Battery At Grasmere Idaho*

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Abstract

Large photovoltaic (PV) hybrid battery systems such as the one at Grasmere Idaho require special consideration in the area of battery technology, operating environment, and maintenance because the system is continuously deep-cycled, the battery voltage is at or above 240 volts, there are a large number of cells, the site is in a remote location, and there is limited power and water for temperature control. In this application, a new C&D CPV deep-cycle low antimony/selenium vented battery was selected for its deep-cycling ability, low maintenance, additional electrolyte reserve, nonconductive plastic trays, and its ability to operate within a wide temperature range without overheating. Laboratory cycle testing has identified a charge profile that improves charge efficiency by extending the taper-charge interval to every 6-days. Using the 6-day taper-charge interval, the field test data from Grasmere has confirmed that the battery will maintain original capacity, require reduced maintenance, and operate within a wide temperature range.

Introduction

PV hybrid power systems are a relatively new application for motive power deep-cycle batteries. This application requires continuous deep-cycle operation, voltages well over 48 volts, high watt-hour battery capacity, and temperature ranges well above and below room temperature. To accommodate these battery requirements, special consideration in the areas of battery selection, ground fault management, temperature control, charge control, hydrogen venting, and maintenance is required.

The Grasmere PV hybrid power system is a remote electronic warfare site used by Mountain Home Air Force base in southern Idaho (see Photo 1). The PV hybrid system was designed and installed by Idaho Power with support from Sandia National Labs and is maintained by Scott Gates of Idaho Power for the Air Force [1,2]. Two 210 kW diesel generators and a 75-kW Solarex PV array provide system power for the 30 to 90 kW site load. An Advanced Energy Systems (AES) 100 kW inverter converts the DC battery energy into AC power and provides system control for battery charging and diesel generator operation. The system has been in continuous operation since 1996 and received a new battery in December of 1999. The new battery is a 240 volt 1.44 MWh C&D model number CPV-2340 low antimony/selenium deep-cycle battery. The battery is configured in three parallel strings rated at 1,935 Ah each to 1.85 V per cell at the 12 h rate.

Photo 1: Grasmere Idaho

The Grasmere Idaho PV hybrid site is being monitored to evaluate the system design and performance of critical components. Previous experience with PV hybrid systems has identified the battery and charge controller as one of the most common sources for performance problems [3]. This evaluation is part of an effort to improve system design, charging strategies, and battery technology for PV systems to reduce life-cycle cost using both laboratory and field test data. Field battery performance was documented by an initial capacity test in February of 2000 and two more tests in April of 2001 and April of 2002. The battery maintenance requirements and reliability are also an important element obtained from the field testing. This work is intended to help the PV and battery industry identify appropriate PV batteries and thus reduce PV hybrid life-cycle costs.

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Laboratory and Field Test Results

Laboratory testing on the C&D CPV battery was used to evaluate an extended interval taper-charge as a way of improving battery efficiency and reducing maintenance. The PV hybrid battery test procedure developed at Sandia National Labs was used to establish maximum charging intervals, charge voltages, and taper-charge time [4]. The test results indicate that the battery will require a taper-charge at 2.55 V per cell for about 6 h every week to maintain capacity. If taper-charge intervals are extended to one month, then battery capacity dropped by 25% in the first month. This is demonstrated in Figure 1 where the weekly taper-charge is the 5-Cycle Deficit-Charge interval and the capacity is at about 96% of the initial value. The monthly taper-charge is the 20-Cycle Deficit-Charge interval and the capacity is about 75% of the initial value. The taper charge interval is important to maximize charge efficiency, reduce battery temperature, and improve system economics.

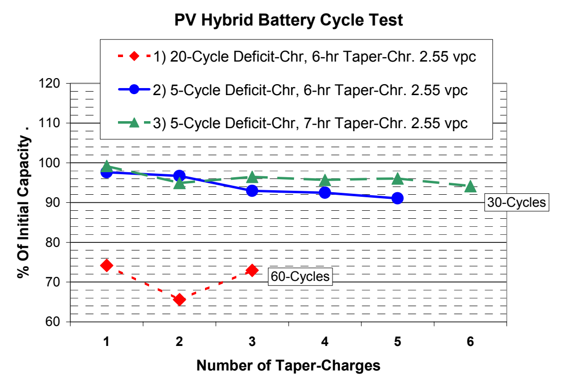

Fig. 1: Laboratory PV Hybrid Battery Test

The field test results at Grasmere verified battery performance under actual operating conditions. These conditions included continuous deep-cycling between 46 and 61% depth of discharge (DOD), temperatures between 16° and 41°C, daily bulk-charges to 2.35 V per cell and weekly taper-charges at 2.55 V per cell for 5 h. The daily bulk-charges to 2.35 V per cell are set to a lower than normal voltage to protect the battery from excessive charging. This low bulk-charge voltage protects the battery when the generator is running to support loads over 80 kW. At high power levels the inverter will maintain battery voltage at the bulk-charge voltage indefinitely or until the load drops below 70 kW.

The test results in Table 1 show that the temperature compensated battery capacity was initially at about 1,899 Ah/string at 1.85 V per cell and after more than two years capacity was measured at 2,047 Ah/string. This is a slight increase in capacity and is consistent with the temperature compensated specific gravity (SG) measurements of 1.271 and 1.295 for the same time period.

Table 1: Summary Battery Data From Grasmere.

Test Date	Avg. SG	Measured Capacity Ah	Discharge Rate Amps	Battery Temp. °C	Temp. Compensated 25°C Capacity Ah	% Of Initial Capacity
2/2000	1.271	1,736	-153 to -161	17	1,899	NA
8/2000	1.276	NA	NA	41	NA	NA
4/2001	1.261	1,674	-125	23	1,697	89
9/2001	1.279	NA	NA	39	NA	NA
4/2002	1.295*	1,846	-111 to -127	16	2,047	108
5/2003	1.280	NA	NA	25	NA	NA

*Measured when electrolyte level was low at 1/3 of full mark.

These results are very close to the manufacturers capacity specification of 1,935 Ah at 1.85 V per cell at the 12 h rate. The drop in capacity measured in April of 2001 is attributed to lower wintertime battery temperatures and a shorter 4 h taper-charge. The lower temperatures and shorted taper-charge reduce the ability of the battery to be recharged.

The daily AC system efficiency measurements during April and May of 2001 and 2003 were both at 86%. The daily system efficiency is an averaged value, which includes generator only operation, inverter only operation, and generator with inverter battery charging operation. The inverter efficiency at operating power levels is in the low 90% range, and the average battery Wh efficiency for 2001 and 2003 was measured at 87 and 81%. The high battery Wh efficiency is critical for minimizing temperature rise on charge, reducing energy costs, and minimizing maintenance.

Photo 2 shows the battery room where there are several battery installation features that improve maintenance and hydrogen venting. These features include sufficient working space, individual plastic cell trays, string disconnects, and a high ceiling for hydrogen venting. Working space is always important for a large battery installation. It's important to be able to use heavy equipment such as fork lifts to move cells when required and it is also useful to have space available for future expansion. The single cell plastic trays are very important to minimize temperature rise and ground faults that can result from conductive electrolyte on the surface of the battery and conductive tray. Electrolyte on the surface of the battery is a very common occurrence. String disconnects make it easy to conduct string maintenance without shutting down the system. If cell failures occur, sometimes having extra cells on float can make cell replacement quick and easy, but it's important to consult with the battery manufacturer to determine if floating extra cells is appropriate.

Photo 2: C&D CPV Battery System

The CPV battery maintenance interval, which consists of cell watering, cell voltage measurements, and inspection for corrosion every 3 to 6-months, has identified one failed cell out of 360 cells after 2.5-years, a number of corroded terminals, and faulty vent caps that sprayed electrolyte over the top of the cell. Once the cell and vent caps were replaced, only light battery terminal corrosion continues even with battery terminal grease. At Grasmere, three cells are maintained on float just in case of more cell failures. Typically, cell failure will occur early and late in the life of the battery. The previous Grasmere battery experienced numerous cell failures toward end of life.

In Figure 2 is a plot of 15 cell temperatures, ambient temperature, and cell voltage. The plot shows that during peak ambient temperatures near 32°C, a taper-charge to 2.50 V per cell will result in a maximum cell temperature of 41°C. After the taper-charge, cell temperatures return to between 30° and 36°C. This temperature range is near the operating limit for vented deep-cycle batteries. If high antimony deep-cycle vented batteries were used, then temperatures would be higher under the same conditions. Valve regulated lead-acid (VRLA) batteries would not be recommended for use at these temperatures. The CPV battery with its low antimony/selenium grid alloy does manage to stay within acceptable temperature limits. Only limited temperature control in the battery room has been implemented because of the increased power requirements for refrigerated air-conditioning and the additional water requirements for evaporative coolers.

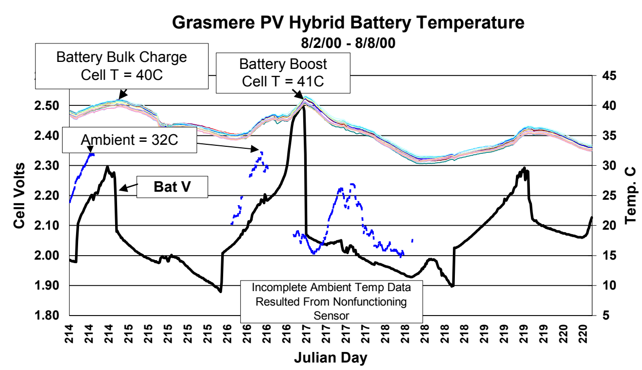

Fig. 2: Grasmere Battery Temperature

Lessons Learned

The above test results show that with proper system design and battery technology large vented deep-cycle battery systems can operate reliably with a minimum of maintenance within a wide temperature range. Below is a list of design considerations, lessons learned, and battery system maintenance requirements.

1) The vented lead-acid low antimony/selenium grid alloy battery technology has enhanced battery performance in a number of areas over traditional high antimony deep-cycle motive power batteries. The battery enhancements include:
    a) Lower water consumption due to reduced electrolysis,
    b) Lower operating temperature due to reduced electrolysis, individual cell trays, and cell spacing,
    c) Lower hydrogen evolution due to reduced electrolysis,
    d) Extended maintenance interval due to reduced electrolysis and increased electrolyte reserve,
    e) Improved battery efficiency due to reduced electrolysis and extended interval taper-charging,
    f) Improved ground fault protection due to plastic cell trays.

2) Battery installation and battery room design have improved the ease of maintenance, battery performance, and thus system reliability. The battery room enhancements include:
    a) Access to cells is easy, safe, and does not require reaching over any other cell,
    b) Replacement of cells is quick, safe, and easy with single cell trays and string disconnects,
    c) A spacious battery room allows for improved hydrogen ventilation, access with a fork lift, and spacing for additional cell cooling,
    d) The battery room does include a hydrogen detection system with ventilation control, but is rarely used because of the battery and the size of the room,
    e) Battery temperature control in the battery room is limited, but does include a ventilation system and a heating system to keep the battery temperature from extremely low or high temperatures while maintaining uniform cell temperatures.

3) Battery operation and maintenance is critical to the success of the system and should include at a minimum the following.
    a) After initial installation, the battery should be inspected for tight interconnects and electrolyte level should not be at the full level. The initial charge will cause the electrolyte level to rise and overflow if the electrolyte level is full before charging.
    b) An initial charge recommended by the battery manufacturer should be conducted before the battery begins service. Cell voltage at the initial regulation voltage should be measured and within specification as prescribed by the manufacturer. String currents should also be measured to ensure balanced strings. If all cell voltages and string currents are within specifications, then the battery is ready for operation. If cell voltages and currents are not within specification, then the manufacturer should be contacted for instructions on how to proceed. Cell watering can proceed after the initial charge.
    c) A manufacturer approved battery charge profile is recommended to ensure proper battery charging. PV hybrids can present significant challenges to battery charging because of the limited available energy and the high cost of that energy used for battery charging. The unpredictable nature of the PV energy resource is also a significant battery charging factor that needs to be accommodated with appropriate engine generator charge control.
    d) The battery maintenance interval will be determined by the battery technology and use environment. Contact the battery manufacturer for recommended maintenance procedures. Common battery maintenance requirements include cell watering after charge, cell voltage measurements at regulation voltage and on discharge, and inspection for loose connections and corrosion. Cell replacement may be required over time, especially after installation and near end of life. Replacement cells on site may be necessary depending on battery technology, cell availability, and system reliability requirements.

Acknowledgments
The authors would like to acknowledge the support of Mountain Home AFB for providing the necessary onsite support to test and evaluate the Grasmere PV hybrid battery system, Andrew Rosenthal from the Southwest Technology Development Institute for data acquisition, and Rick Chapman from Sandia National Labs for his work with system design and battery selection.

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This project was sponsored by the U.S. Department of Energy and administered by the Energy Storage Systems (ESS) Program at Sandia National Laboratories. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.